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UTILIZATION OF AMERICAN FLAX STRAW IN THE PAPER AND FIBER-BOARD INDUSTRY.

By Jason L. Merrill, *Paper-Plant Chemist, Paper-Plant Investigations.*[1]

CONTENTS.

INTRODUCTION.

The purpose of this paper is to report recent tests on the utilization of American seed-flax straw in the paper and fiber-board industry. Successful commercial tests have been completed, wherein domestic flax straw and tow were used in place of imported flax waste in the manufacture of fiber counter boards, which are employed to a great and increasing extent in making toe boxes and counters for shoes. The boards made during these tests were pronounced satisfactory by manufacturers and were sold to the trade at the regular price for such boards.

From an economic point of view it seems inconsistent that this country should import flax waste from foreign countries for paper and board manufacture and at the same time actually burn one and one-half million tons of flax straw which is raised within its own borders. The reason usually given and naturally assumed is that it is more profitable to use the foreign article or that the domestic material is not suitable for the purpose. It will be shown in this report that these reasons have not been well founded.

[1] The work of investigating flax straw as a paper-making material was initiated by Mr. Charles J. Brand, now Chief of the Office of Markets and Rural Organization, when he was Physiologist in Charge of Paper-Plant Investigations of this bureau. Mr. Brand still retains supervision of this line of the bureau's activities.

NOTE.—This bulletin gives an account of recent work on the utilization of American seed-flax straw in the paper and fiber-board industry and will be of interest to chemists, flax farmers, counter-board manufacturers, and paper makers in general.

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Among other reasons why flax straw should be investigated as to its paper value there should be cited the present condition and tendency of our rag paper-stock supply, which would welcome new sources of material at this time. About 70 per cent of the rags used in paper manufacture in the United States are imported from European countries. It is well known that very good writing papers have been produced from flax straw, but the cost of the processes employed up to the present time has not been justified by the quality and value of the product.

The rope-paper and high-grade sack-paper manufacturers also have been consuming an immense quantity of foreign raw material, in spite of the fact that it is known that American flax straw is capable of being used for some of these purposes. But here again the product has not justified the cost of the process. Manufacturers of cartridge or shot shell papers annually import approximately 2,000 tons of flax waste for the production of their paper, and the question of a satisfactory substitute is engaging their attention. From the paper maker's point of view, therefore, the flax crop represents a raw material of immense latent value, and, as will be shown, it is likewise a source of great latent value to the flax farmer.

Certain promoters have made attempts to exploit this material, but their efforts often have been based upon insufficient evidence and data. It is the object of this paper to show to what extent flax straw may be utilized in the paper-making and fiber-board industries and to suggest further possibilities.

One of our most highly prized and valued oils and one for which no satisfactory substitute has been found is linseed oil, which is manufactured solely from the seed of the common flax plant (*Linum usitatissimum*). The raising of flax is an industry of great importance, as is shown by the fact that the United States normally[1] has about 2,200,000 acres devoted to its culture, which produce about 20,000,000 bushels of seed, valued at approximately $33,000,000. This seed flax of the Northwest is different in type from that cultivated primarily for fiber production, and because of this difference and the methods of cultivating and handling the crop the straw can not be made to produce a good spinning fiber.

The straw resulting from the harvesting and thrashing of this crop usually is burned, not because it has no intrinsic value, but because no adequate industrial use has been established to absorb it. With a production of three-fourths of a ton of straw per acre, the total annual tonnage of straw amounts to approximately 1,600,000 tons, of which not more than 200,000 tons are at present put to any profitable use.

[1] Five-year average, 1909 to 1913.

The utilization of the remaining 1,400,000 tons would be of immense economic importance, since (1) its paper-producing possibilities are equal to the annual production of wrapping paper and more than double the annual production of writing paper in the United States; (2) its sale would represent an added revenue to the farmers of about $5,000,000 annually; (3) it would exert a very strong tendency toward maintaining the flax crop in our agricultural system; (4) it probably would result in the establishment of paper-manufacturing industries in sections where there are none; (5) it would aid in making our paper industry more independent of foreign raw paper-making materials; and (6) it would produce a keener realization of the latent value of some of our enormous crop wastes.

MIGRATION OF THE FLAX CROP.

The acreage of the flax crop has not remained permanent in any one section, and it is this constant migration which is of as vital importance as is its total available tonnage.

The total crop is variable in acreage and yield to the extent shown by Table I.

TABLE I.—*Acreage and yield of the flax crop in the United States for 1899, 1902, and from 1909 to 1914, inclusive.*

Year.	Acres.	Bushels of seed.	Year.	Acres.	Bushels of seed.
1899	2,110,000	19,979,000	1911	2,757,000	19,370,000
1902	3,740,000	29,285,000	1912	2,851,000	28,073,000
1909	2,083,000	19,512,000	1913	2,291,000	17,853,000
1910	2,467,000	12,718,000	1914	1,885,000	15,559,000

During its entire history flax has been a pioneer crop, being used as a first crop on the upturned virgin soil. This soil is claimed to be too rich for corn and other cereals, but, on account of the very meager root system of the flax plant, it thrives here at its best. Flax does not do as well on the same land until after other crops have been raised and the land put into grass again, when it is ready to be broken up for a new flax seed bed. The old prevalent idea that the flax crop is very exhausting to soil fertility has been shown to be a fallacy,[1] and it has been proved that it does not tax the soil fertility as much as either wheat or oats.

Table II gives statistics of flax acreage which show the migration of the crop in certain States since 1899.

[1] Bolley, H. L. Flax culture. N. Dak. Agr. Exp. Sta. Press Bull. 46, 4 p., 3 figs. 1911.

Bull, C. P. Flax growing. Minn. Farmers' Libr. Ext. Bul. 27, 8 p., illus. 1912.

TABLE II.—*Area devoted to flax in certain States in 1899, 1909, and 1913, showing the migration of the crop.*

State.	1899	1909	1913	State.	1899	1909	1913
	Acres.	*Acres.*	*Acres.*		*Acres.*	*Acres.*	*Acres.*
Ohio	3,092	552	....	Iowa	126,453	15,549	28,000
Illinois	394	115	....	Minnesota	566,800	358,426	350,000
Kansas	192,167	45,014	60,000	North Dakota	774,000	1,068,049	1,000,000
Nebraska	7,652	2,934	9,000	South Dakota	302,010	518,566	425,000
Michigan	883	261	....	Montana	16	37,647	400,000
Wisconsin	11,263	9,423	9,000				

In 1879 Illinois, Iowa, and Indiana were the leading flax States. From present indications Montana is forging ahead very rapidly as a leading flax State, and Kansas and Nebraska also are becoming larger producers.

Since North Dakota is the largest flax State, the effect of migration in that State since 1902 has been determined. A north and south line of counties in the extreme eastern end of the State and a similar line of counties in the extreme western end have been chosen for comparison (Table III), to show the effect of migration.

TABLE III.—*Area devoted to flax in the eastern and western sections of North Dakota, in certain years, showing the westward migration of the crop.*

Year.	Number of acres in flax.		Percentage of total flax acreage of the State.	
	Eastern counties.	Western counties.	Eastern counties.	Western counties.
1902	892,000	145,400	47.0	7.6
1905	498,800	208,090	42.3	17.6
1910	267,000	404,200	23.6	35.7
1914	188,240	325,700	26.7	46.2

The figures in Table III show very clearly that the crop has migrated westward across the State and that in twelve years the eastern and western sections have changed places in relation to the total flax crop of the State. It naturally might be inferred that the crop will migrate eventually entirely out of the State, but, because of the short distance to the Rocky Mountain region and the Canadian line and because of increased knowledge of successful flax raising, it seems very probable that flax will continue to be an important crop in this State and region for a considerable period.

FLAX STRAW IN THE PAPER AND FIBER-BOARD INDUSTRY.

UTILIZATION OF FLAX STRAW IN THE PAPER INDUSTRY.

There is a great diversity of opinion as to the possibility of economically manufacturing paper from flax straw, but there is an almost unanimous agreement that it contains a certain proportion of

fiber which would be of value could it be separated economically from the straw. Different requirements are made of a raw material, however, depending on the grade of product desired. It might, for example, meet the requirements of the board manufacturer in regard to product and cost and not be capable of interesting the writing-paper or wrapping-paper manufacturer, for reasons of product or cost, or both. It may be found also that the straw can be used in only one or two grades of product, as is the case with poplar wood and esparto grass.

Much work has been done by different experimenters in testing this straw for its paper value, and samples of writing and sack papers have been produced which, so far as quality is concerned, seem to be satisfactory. A small flax-tow mill is in operation in North Dakota, which is equipped with a pulping boiler, beater, and other apparatus, and it has produced bleached flax pulp of an apparently satisfactory quality, from which good grades of writing paper have been manufactured. But the work, although promising, is yet in the experimental stage.

In 1908 the Bureau of Plant Industry, cooperating with the United States Forest Service, conducted a number of pulp-making tests with the straw and found that a very severe chemical action was required and that it was impossible to bleach the pulp economically with ordinary bleaching-powder solutions.

In spite of all the activity in this direction, however, no industry has been established whereby paper manufacturers have been enabled to utilize this immense and valuable crop waste.

UTILIZATION OF FLAX STRAW IN THE FIBER-BOARD INDUSTRY.

In the manufacture of certain grades of fiber board known as counter board, one of the main constituents is flax waste from the textile industries of Europe. The total quantity so used in this country is approximately 7,000 tons per annum. This waste is divided into four distinct classes, namely, flax card waste, flax card strippings, flax rove waste, and flax washed waste, depending on the particular operation from which each is derived. These wastes, with the exception of the washed waste, have a certain amount of flax wood shives associated with them, the card waste containing the most and the rove waste the least. The washed waste contains no shives and is the highest priced; likewise, the least used in board manufacture.

As to the possibility of substituting domestic flax straw for the imported flax waste, a comparison from a chemical and physical standpoint brings out the following facts:

(1) Flax waste is derived from retted flax straw and consequently contains very little of the mucilaginous pectin compounds, such as

are present in domestic unretted flax straw. For this reason alone flax straw would require the use of more chemicals in its reduction than does flax waste.

(2) The proportion of wood in flax straw is far higher than in flax waste, which probably would necessitate a higher consumption of chemicals in treating the former. If it should appear necessary to exclude wood shives from the finished product, it might be found necessary to reduce the wood to a greater extent than when using flax waste, in which case the reduction might require the employment of a higher steam pressure or a longer time of treatment, or both.

The greatest difference in a physical sense between straw and waste is that the former, being composed of lengths of the whole stalk, presents larger pieces, or masses, to the action of the chemicals, thus necessitating the employment of more time in the chemical reduction process. These chemical and physical differences, however, do not differ in kind but only in degree, from which it would be concluded that the method found to be satisfactory with straw would differ in no fundamental manner from that known to be satisfactory with waste.

LABORATORY EXPERIMENTAL TESTS ON THE PREPARATION OF PULP.

In March, 1914, preliminary work was started by the Department of Agriculture on the utilization of flax straw as a raw material for sack or wrapping paper manufacture. It was decided that, of all the fiber-treating processes, the milk-of-lime process was the most worthy of trial, after the following factors, among others, had been considered carefully:

Lower initial cost of factory installation.—On account of freight rates, which figure so prominently in the final costs of manufactured products, and because of the remoteness of the flax region from paper mills, it might appear advisable to establish pulp or paper mills nearer the source of raw-material supply. It would be inadvisable to install a process which demands a heavy expenditure per ton, such as the soda, sulphate, and sulphite processes, before the true value of the material were proved by actual manufacture for a reasonable period of time. Such a practical test might be prohibitive because of the shipping cost for such a distance, and few, if any, manufacturers could be expected to operate at a loss or even at a low profit for a sufficient period to determine the advisability of factory installation. The same remarks apply to the milk-of-lime process, but not to the same degree.

Tensile strength of the fibers preserved.—As is commonly known, caustic soda pulping lowers the tensile strength of fibers more than the milder milk-of-lime process.

Class of employees required.—The milk-of-lime process does not demand the employment of as large a staff or as great a variety of skilled help as the soda, sulphite, or sulphate processes.

The laboratory work consisted of pulping tests, beating and washing the pulp and making it into hand sheets. From the data gathered during this process and from the samples conclusions were drawn as to procedure and conditions to be employed on subsequent semicommercial tests. It is fully realized that in general it is impossible to duplicate commercial working conditions on a small laboratory scale; therefore, laboratory results, valuable as they may be, should be interpreted commercially only with extreme caution. The following laboratory work and results are regarded, therefore, as approximate indications, to assist in subsequent semicommercial tests.

The flax straw used in these tests was of the ordinary seed-flax type raised in the vicinity of Fargo, N. Dak., was thrashed with the ordinary thrashing machine, as is the practice in that section, and was baled in an ordinary hay baler. The bales contained their proper complement of chaff, usually 30 per cent, and averaged 80 pounds in weight.

To serve as a fiber suitable for paper manufacture it is necessary to reduce the woody portion by cooking or bleaching to such a condition that the beater will be able to disintegrate mechanically or separate the woody shives to such a size or condition that they may be removed from the true fiber by washing in the regular manner. The proportion of woody matter that it is necessary to remove depends naturally on the grade of product desired.

Pulping tests, technically known as "bleaches," were conducted in an iron rotary boiler of 10 gallons capacity, heated by means of direct steam and gas burners, and rotating 1 revolution per minute.

In conducting a bleach, the boiler is charged full of straw, from which a sample has been drawn for a moisture determination, in order to calculate the weight of bone-dry straw employed. The predetermined quantity of lime (burned lime), calculated in percentage of the bone-dry straw, is added in the form of milk of lime, together with sufficient water to amount to 1 gallon per 2½ pounds of straw. After closing the boiler and rotating a few times, direct steam at 110 pounds pressure is admitted, the gas urners underneath are lighted in order to counteract excessive radiation, and the charge is heated to a certain point in one hour.

The control of the degree of heat in a boiler is accomplished in practice by a steam-pressure gauge which bears a direct relation to the temperature of the charge, but since it is not pressure but temperature which induces the chemical actions, it would obviously be as correct to employ temperature as pressure for a guide. In all of the laboratory work the temperature control was used, being effected by a thermometer inserted in a horizontal well extending from the end of the boiler to the center of the charge. After the desired tem-

perature has been reached this degree is maintained constantly for the required number of hours, after which the burners are removed and the boiler cooled in about half an hour by means of a small stream of water applied to the boiler shell. The resulting stock, on removal from the boiler and after remaining unwashed over night, is well washed with water, pressed into a uniform cake, weighed, and a sample drawn for a moisture determination, from which data the yield of total stock is determined.

The stock after bleaching shows the bark more or less completely resolved and the bast very loosely held in the structure. The inside woody portion appears practically unchanged, but in reality it has

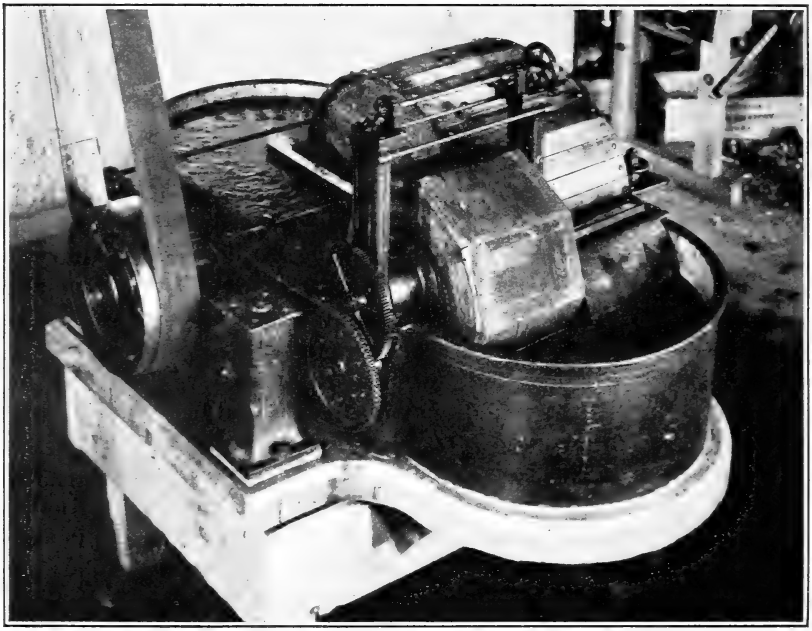

FIG. 1.—Experimental 10-pound beater, supplied with washer.

suffered a chemical and physical change whereby the structure is mechanically weakened.

Next, the stock is "beaten" in an experimental 10-pound beater (fig. 1), which consists of a trough in which the stock is caused to circulate and pass between a bedplate of coarse knives or bars and a series of similar knives set in the periphery of an iron roll making about 150 revolutions per minute. The distance between the two sets of knives can be regulated and altered to any degree, according to the effect desired. This action causes the bleached stock gradually to be distintegrated into its ultimate cells, the bark being reduced to bast cells and the small connecting cells of the structure and the

woody portion partly to very fine shives and partly to the ultimate wood cells.

The measurements shown in Table IV give an idea of the kinds and relative sizes of the various cellular elements of which flax pulp is composed. The pulp in this case was obtained by the soda process, on account of the more complete separation of the cells in the pulp (fig. 2).

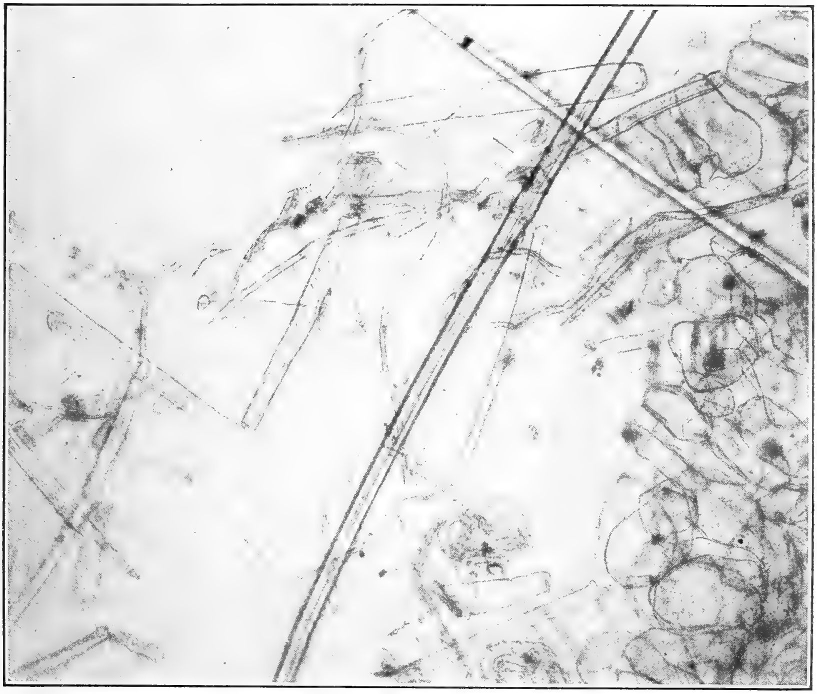

FIG. 2.—Microphotograph of pulp from flax straw before the smaller cells are removed. (Magnified 103 diameters.)

TABLE IV.—*Dimensions of the cells of flax pulp.*

Kind of cells.	Dimensions (millimeters).						Ratio of length to width.
	Length.			Width.			
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	
Pith cells (from the central portion of the stalk)	0.14	0.08	0.10	0.08	0.06	0.06	1.5
Epidermal cells	.11	.07	.08	.03	.01	.02	4.3
Short parenchyma cells	.13	.09	.11	.02	.01	.02	7.2
Long parenchyma cells	.40	.18	.29	.04	.02	.03	9.2
Spiral, pitted, and other vessels	(1)	(1)	(1)	.02	.009	.011	....
Wood fibers (from the woody portion of the stalk)	.426	.16	.20	.013	.009	.011	17.5
Bast fibers (the long fiber of the plant, which is of value to the paper maker)	64	5	....	.039	.010	.019	....

[1] Extending throughout length of plant.

The short fibers or cells are not sufficiently long or correctly proportioned and shaped to possess the felting quality on which their value largely depends in paper manufacture; moreover, in distinction from the long bast fiber, they are liquefied, which renders them very undesirable in the manufacture of durable products.

The separation of the dirt and short fibers from the long true fibers was accomplished in the laboratory, as in practice, by means of a washer, which is a rotating drum covered with 20-mesh wire cloth on the sides and having helical scoops inside connecting with a hollow trunnion. This washer is attached invariably to the beater and by being lowered about one-third its breadth into the circulating stock it removes water, dirt, and short fiber, while fresh water is admitted at the other end of the beater.

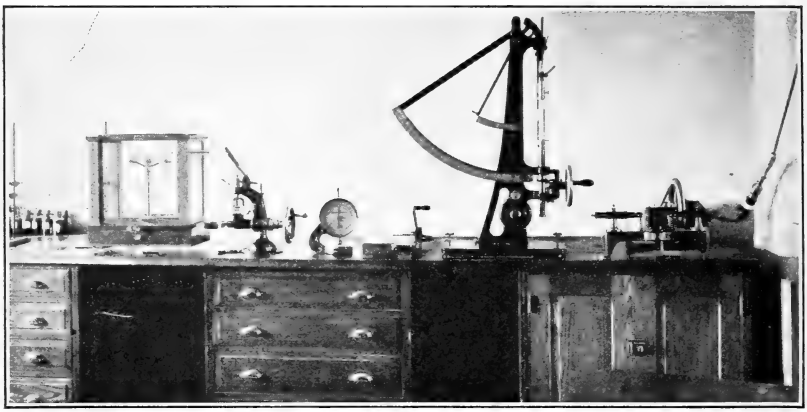

FIG. 3.—Paper-testing machines in a constant-humidity room.

Obviously, this light beating and washing should be carried to different degrees, depending on the quality of the product desired. For example, a medium grade of fiber board would not require as much washing as one of higher grade and a stock suitable for wrapping or sack paper would require a very complete washing.

After having been washed to the desired degree, the stock is drained from the beater, pressed, weighed, and sampled for a moisture determination, in order to calculate the yield of the washed fiber. It is then returned to the beater, and the long true fiber is reduced to a degree which is suitable for manufacture into a sheet of paper.

All sheets were made waterleaf on a hand mold $5\frac{1}{2}$ by 10 inches, dried on a steam-heated cylinder at 105° C. under a definite tension, and subsequently given physical tests under constant conditions of temperature and relative humidity.

To show the effect on the physical constants of a paper caused by drying the wet handmade sheet under different tensions, the re-

sults of one series of tests on a lime-cooked flax-straw paper are here given (Table V). The wet sheets were placed on a cloth-covered iron cylinder heated by steam to 103° C. and held down by placing on top a cloth which was maintained at a definite tension. The sheets shrank more and cockled more under a light tension than under an increased tension. The physical tests were made at 80° C. and 65 per cent relative humidity (fig. 3).

TABLE V.—*Effect on the physical constants of paper dried under different tensions.*

Tension of cloth.	Breaking length of sheet (meters).	Folding factor of sheet, ream 25 by 40 by 500.
550 grams	3,165	0.00312
1,245 grams	3,420	.00407
2,155 grams	3,810	.00487
3,240 grams	4,150	.00571
3,700 grams	3,960	.00405

From Table V it appears that within certain limits the strength and folding quality of a sheet depend to a considerable degree upon the method of drying.

Bleaches were made with from 12 to 25 per cent of burned lime, calculated on the bone-dry weight of the straw used, employing temperatures from 135° to 170° C. and treating at the definite temperature from 6 to 10 hours.

The most thorough reduction and generally satisfactory results were obtained with 14 per cent of lime acting for 10 hours at 170° C., or the equivalent of 100 pounds steam pressure. The yield of total fiber obtained did not vary much with the different bleaching conditions, ranging from 60 to 68 per cent of the bone-dry weight of the original straw employed. Determinations of the yield of washed or separated fiber on the satisfactory bleaches gave an average of 32 per cent of the bone-dry weight of straw employed.

MILL TESTS ON THE MANUFACTURE OF WRAPPING PAPER.

Tests of wrapping paper from flax straw were made at Cumberland Mills, Me. Semicommercial machines were used, and most of the work was performed by the regular mill employees.

The straw used in these tests was raised in the vicinity of Fargo, N. Dak., being the same as that used in the laboratory tests. It was first sieved on a 4½-mesh screen, in order to remove the loose chaff composed of dirt, seeds, and empty seed capsules, which amounted in total to 24.5 per cent of the original straw.

Chemical reduction was effected in a steel, rotary pulp boiler, 6 feet long by 4 feet in diameter, which was supplied with a thermometer well, pressure gauge, and pipes for relief and direct steam inflow.

Bleach No. 193.—A charge of 277 pounds (242 pounds, bone-dry weight) was treated with 15 per cent of burned lime (36.4 pounds) and 100 gallons of water, the lime being slaked in part of the water before being added. Direct steam was admitted, so as to bring the charge up to 148° C., or 50 pounds steam pressure, in 1 hour; then regulated so as to maintain this pressure for 10 hours, after which the pressure was relieved and the contents removed. This stock was followed down with a fairly light roll and washed for 3 hours in a 400-pound beater, at which point the stock was removed, drained, pressed, weighed, and sampled for moisture content. From these data the yield was found to be 64.6 per cent of the sieved straw, or 48.7 per cent of the original bone-dry straw.

Bleach No. 194.—This bleach was made in the same manner as No. 193 and beaten and washed 3 hours, after which the stock from No. 193 was added to it in the beater. The combined stocks were beaten a total of 19 hours, the last 7 of which were fairly hard, the washer being used the first 4 hours. The long bast fibers were very strong and not easily reduced; likewise, the woody portion did not completely reduce to the separated individual fibers, but remained as more or less fine shives, or cell aggregates. The washer used in this work was 60-mesh, while a much coarser, possibly 20 or 25 mesh, would have removed many more of the shives and given a far better product. This unsized and unscreened stock was pumped to the stuff chest and run over a 30-inch Fourdrinier paper machine, in conjunction with a Jordan type of refiner. The stock acted well on the machine wire, was strong after the second press rolls, did not cockle on the driers, but became very brittle on drying, doubtless due to the large amount of woody shives present. It was apparent that more wood must be removed from the finished product. This could be accomplished by removing it from the straw before treatment, or by more severe chemical treatment, or by a harder beating and washing. Another test was made on the same lot of straw, which gave a sieving loss of 35 per cent of the original straw.

Other bleaches.—Three bleaches, Nos. 202, 203, and 204, were made, similar to bleach No. 193, using 14.7 per cent of lime and treating 10 hours at 160° C., equivalent to 60 pounds steam pressure.

The stock from bleach No. 202 was beaten and washed eight hours in a 400-pound beater, following the roll down fairly hard. At this point the stock was removed and weighed, giving a yield of 63.8 per cent of the sieved straw, or 41.5 per cent of the original bone-dry straw.

Stock from bleaches Nos. 203 and 204 was beaten and washed $7\frac{1}{2}$ hours, after which the washed stock from bleach No. 202 was added and the whole beaten and washed for 18 hours. The feeling and appearance of the stock improved during the whole beating and washing period, but it was still apparent that not enough wood was being removed. Competent employees judged that there were 250 to 300 pounds of stock in the beater at this point, which would represent a yield of 40 to 47 per cent of the sieved straw, or 26 to 30.5 per cent of the original dry weight of straw.

The stock was sized with 1 per cent of size and 3 per cent of alum and run over the Fourdrinier paper machine at a speed of 91 feet per minute. The stock acted very well on the machine, but, as in the previous test, the sheet became brittle on drying. It was evident that a still harder or different bleach was necessary or that the manner of beating and washing should have been different.

MILL TESTS ON THE MANUFACTURE OF FIBER BOARD.

When the experimental work on the utilization of flax straw in the manufacture of paper had reached this point, there was a great uneasiness in the fiber-board industry concerning the supply of foreign raw material because of the outbreak of the European war. As previously noted, there are imported into the United States annually about 7,000 tons of flax waste derived from the foreign textile industries, which are used almost exclusively in the manufacture of the counter-board grade of fiber boards. These counter boards are used chiefly for the manufacture of counters and toes for the stiffening of the heels and toes of shoes.

The price of this flax waste has ranged from \$25 to \$29 per ton from 1908 to 1912, inclusive, and the average price in 1913 was \$36.50. The waste had been constantly deteriorating in quality, until the same grade was 20 to 25 per cent poorer for fiber-board manufacture than in 1908–9. Soon after war was declared the available supply of flax waste was bought up and stored for future manufacture, and the importations were greatly curtailed. Finally, the waste was withdrawn from quotation, after reaching prices of about \$65 per ton.

It was thought that if American flax straw could be substituted for the imported waste, this would be the most propitious time to induce manufacturers to cooperate in the work and establish a market for this crop waste. One of the leading counter-board factories signified its willingness to cooperate in the project and kindly placed at the disposal of the Bureau of Plant Industry many of its regular machines and its semicommercial testing equipment.

The semicommercial testing equipment consisted of a direct steam, iron, rotary bleach boiler, about 2 feet in diameter by 5 feet in length;

a 10-pound washing and beating engine; and a wet machine capable of producing board sheets 15 by 22 inches.

After several preliminary tests on the small machines it was found that flax straw bleached with 14 per cent of lime for 15 hours at 170° C. and washed and beaten in the regular manner made a board which was almost invariably too hard and brittle, but if used with an equal amount of bleached old mixed string and an equal amount of bleached board cuttings a satisfactory board could be made. Still there was usually a little too much brittleness.

Test No. 115.—A test was then made, designated as No. 115, using the large beater and wet machine. Two charges of 255 pounds each were made in a rotary pulp boiler, bleaching with 14 per cent of burned lime at 170° C. for 15 hours. About 275 pounds, dry weight,

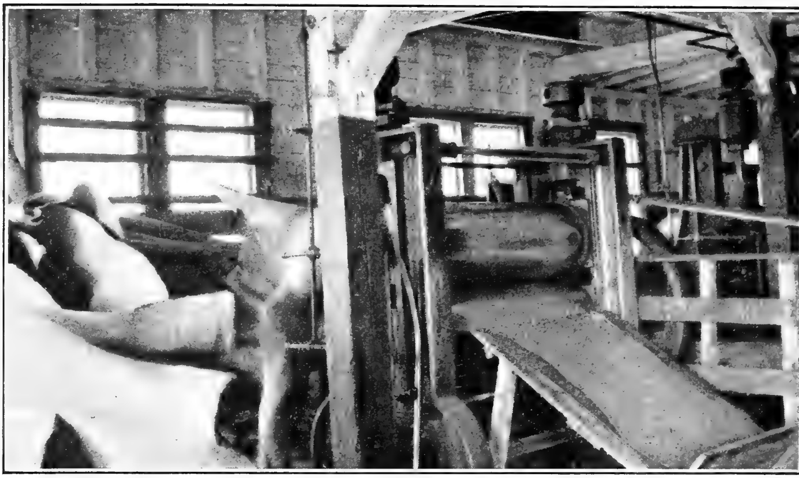

Fig. 4.—Fiber-board press or calender.

of this stock was charged into a 700-pound beater and washed and beaten with a hard brush for $2\frac{1}{2}$ hours, after which the roll was raised and the washing continued one hour longer. The wood was reduced and removed to a considerable extent, and, although the bast fiber was reduced in length somewhat, there was no bast-fiber loss in the wash water. At this point the workmen pronounced the stock very similar in appearance and action to that from flax waste.

The washed flax was then added to a beater containing an equal weight of bleached mixed strings, which had been washed and beaten for seven hours, and an equal weight of bleached board cuttings was added. The furnish therefore was one-third mixed strings, one-third flax straw, and one-third board cuttings. This charge was beaten down, sized, and loaded by the experienced beatermen of the company in the equivalent of 12 hours total time. The stock was run into board on a regular 44-inch wet machine and dried in the loft

for 15 hours, after which it was put through the board calender (fig. 4).

The thin or light-weight sheets were too soft, those of medium weight satisfactory, and the heavy ones a little too brittle. It should be stated that the stock needs to be reduced to different fiber lengths, depending on the weight of board desired. Those boards of this test which were of medium weight and were satisfactory were sold with the company's regular stock and no complaint was received from them.

Test No. 118.—A test was then made, using the large beater and regular wet machine, employing the same furnish as in test No. 115, but the charge of mixed strings was added unwashed to the charge of flax straw, which had been washed for 3 hours. This combined charge was washed for 1½ hours more, when the furnish of board cuttings was added and the charge sized, loaded, and beaten off in a total of 14 hours, or 11 hours after the addition of the strings. The board was tough, but much too soft. The old saying that "the paper is made in the beater" seems to apply equally well to fiber-board manufacturing, as the furnish in this test was the same as in test No. 115 and the difference in the method of furnishing was insufficient to account for the difference in the two products.

Test No. 125.—A test on the large mill machines was now made, including the bleaching in the company's large bleach boiler. Three thousand pounds of the baled straw were pitched over carefully with fine pitchforks and freed from chaff, which amounted to 33 per cent of the original straw. The 2,000 pounds of sieved straw were charged into the boiler, together with 14 per cent of burned lime and 800 gallons of water. The charge was heated by direct steam to 105 pounds pressure in 1½ hours and maintained at this pressure for 15 hours, after which the pressure was relieved in 1½ hours and the charge removed. For some reason the stock did not appear quite as well reduced as was the bleach carried out under the same conditions in the smaller boiler at Cumberland Mills, Me.

A 500-pound beater furnish of one-third domestic flax straw, one-third mixed strings, and one-third board cuttings and sulphite screenings was washed and beaten in the following manner: The flax-straw stock was first washed in the beater for 5 hours, when the mixed-string stock was added, after having been washed for 1½ hours. The charge was beaten 4 hours, when the one-third of board cuttings and sulphite screenings was added and the whole beaten 6 hours more. The furnish was sized and loaded in the regular manner. This stock was run over a 44-inch wet machine, loft dried, and calendered, giving a board which, although not perfectly satisfactory, was readily used in the trade.

It was realized at this point by the officials of the Department of Agriculture and the fiber-board manufacturing company that the

flax straw contained a fiber which was very promising for this line of product, but the woody portion was so high that it offset to a large degree the desirable quality of the bast fiber.

FLAX TOW IN THE FIBER-BOARD INDUSTRY.

CONDITION OF THE FLAX-TOW SUPPLY.

Field work in Minnesota and North Dakota, which was undertaken after these tests were made, developed many factors of direct and immediate value to this project and to the paper and fiber-board industry in general.

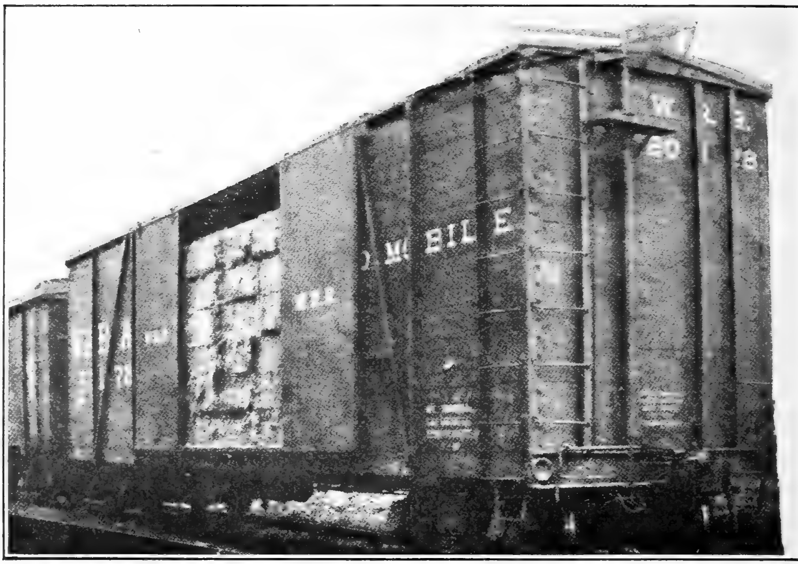

FIG. 5.—A carload of flax upholstering-tow bales.

Of the total quantity of unused flax straw resulting from the thrashing of the flax crop, fully 90 per cent is actually burned in the fields. Farmers located near tow mills are able to sell all of their straw, getting in some sections $2.50 to $3.50 per ton, loose, hauled to the mill. In one section farmers were selling at $1 per ton in the stack. In those sections where flax is raised more abundantly, such as central and western North Dakota, it is the general belief that the baled straw can be delivered f. o. b. cars in large quantity at not more than $4 per ton. (Figs. 5 and 6.)

About the only profitable use to which the straw is put is in the manufacture of flax tow, which is consumed for the most part in upholstering and as a packing material for crockery, glassware, etc. This tow is made from tangled and broken flax straw after it has

been thrashed in ordinary grain-thrashing machines, without retting, and is very different in character from the flax tow of the spinning mills. A comparatively small quantity is manufactured into insulating boards, such as are used in building construction and refrigerator cars; also a very small amount is used in the manufacture of rough twine. There are about 10 flax-tow mills in the flax region, the largest of which consumes over 30,000 tons per year, while some use not more than 1,000 tons.

The flax-tow machines consist essentially of a series of corrugated rollers operating in pairs under considerable pressure, through which a uniform layer of straw is rolled. The woody portion is crushed and broken into small pieces, which fall away between the rolls and are further removed by dusting and screening devices.

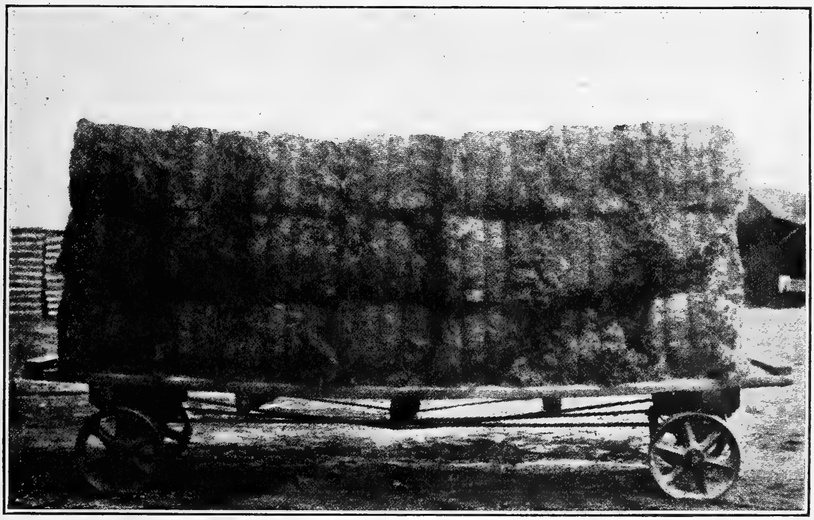

Fig. 6.—A truck load of flax upholstering-tow bales.

Flax upholstering tow is sold under four grades and normally in carload lots at the following prices: Coarse, $16; medium, $18; fine, $24; extra fine, $32. These prices were the quotations in September, 1914, for baled flax tow, f. o. b. St. Paul, Minn., at which point flax straw can be bought at $7 per ton, baled, in carload lots. The different grades vary in the amount of woody matter removed and the degree of softness of the tow (fig. 7).

Considering these prices of tow, the amount of wood removed, and the general physical condition of the material, it would seem that tow would be a more desirable as well as a more profitable raw material than straw for the fiber-board manufacturer, if not indeed for the paper manufacturer. In the case of medium tow, for example, 2 tons of straw are required to make 1 ton of tow, which is a consider-

able item where the material must be shipped east to the board and paper mills, as most of the counter-board mills are in or near New England. It is also a considerable item when it is recalled that the board and paper manufacturer must remove more or less (and in some cases practically all) of the wood during the manufacturing process before a pulp is obtained suitable for his purpose. Moreover, the physical condition of the material is such that it is more amenable to chemical pulping processes, yielding to less expensive processes and producing a more uniform and satisfactory product.

MILL TESTS ON THE MANUFACTURE OF MEDIUM FLAX TOW.

On account of previous and satisfactory laboratory results on flax tow and because of the satisfactory condition of the tow industry near the flax region, it was decided to be advisable in continuing board tests to employ flax tow instead of flax straw, as had been done up to this time. With this in view, a cooperative test was made in

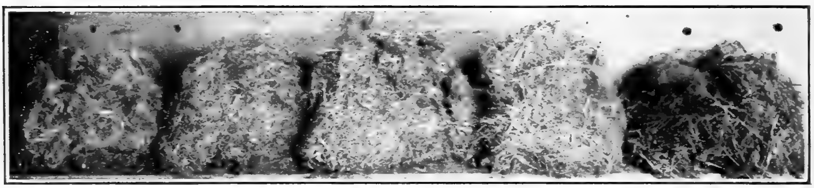

FIG. 7.—Small samples of flax straw and tow. From right to left: Straw, coarse tow, medium tow, fine tow, and extra fine tow.

a large tow mill at St. Paul, Minn., in which 24.8 tons of straw were manufactured into 14.7 tons of medium tow, or 59.3 per cent of the original straw, which yield is believed to be somewhat higher than that obtained in ordinary practice. The bales average 100 pounds, and 15 tons can be loaded into a car. This lot of tow was shipped to a counter-board mill in Maine, where cooperative board tests were made later, while four bales were sent to the Washington laboratory for preliminary tests as to the most suitable method of treatment. From observations made during this tow test, it was evident that by very slight modifications of the tow machinery considerably more woody matter could be removed, greatly to the advantage of the paper manufacturer.

LABORATORY TESTS ON THE TREATMENT OF MEDIUM FLAX TOW.

The tow used in these tests was that manufactured at St. Paul, as previously described. In order to obtain an idea of the amount of loose woody matter still remaining in the tow, a weighed quantity was shaken out lightly by hand, yielding 16 per cent of woody shives. These shives are of no value to the paper or board manufacturer, and

it is believed that they can be removed readily at the tow mills at a very slight increase in the cost of processing the tow.

A series of lime cooks or bleaches was made in the laboratory, employing a 38-liter rotary pulp boiler operated by direct steam, from the results of which it was concluded that a treatment with 14 per cent of burned lime for 4 hours at a steam pressure of 100 pounds per square inch would give a product satisfactory for fiber-board manufacture. Under this treatment, the yield of washed or separated fiber was 48 per cent of the bone-dry weight of tow used.

Table VI gives a partial list of the laboratory bleaches, illustrating the method of determining the correct amount of lime necessary to be used.

TABLE VI.—*List of bleaches, showing the method of determining the correct amount of lime to be used.*

Cook No.	Lime used.	Time of treatment.	Pressure per square inch.	Waste liquor (per liter). Acidity.	Waste liquor (per liter). Soluble lime salts.
	Per cent.	*Hours.*	*Pounds.*	*Grams, acetic acid.*	*Grams, CaO.*
246	12	5	100	0.97	6.8
247	14	5	100	.26	5.8
				Per cent, CaO.	
248	15	5	100	0.008	6.3
249	17	5	100	.023	6.9
250	17	5	100	.024	7.2

The yield on cook No. 250 was 73.8 per cent of total fiber and 48.6 per cent of washed or separated fiber. Washing was done in the beater by means of a regular washer covered with 30-mesh wire cloth, such as is used in fiber-board mills.

A series of bleaches on flax straw is recorded in Table VII, showing the extent to which fiber can be injured by not employing sufficient lime in the bleach.

TABLE VII.—*List of bleaches, showing the extent of injury to fiber through insufficient lime.*

Cook No.	Lime used.	Time of treatment.	Pressure per square inch.	Waste liquor (per liter). Acidity.	Waste liquor (per liter). Soluble lime salts.	Tensile strength of ultimate fiber per square mm. of solid cross section.[1]
	Per cent.	*Hours.*	*Pounds.*	*Grams, acetic acid.*	*Grams, CaO.*	*Grams.*
243	12	6	100	2.11	7.4	....
244	14	6	100	.97	9.1	57,000
245	16	6	100	(2)	7.0	65,000
				Per cent, CaO.		
251	18	6	100	0.006	7.0	....
252	18	6	100	.03	7.5	85,000

[1] Determined by a method devised by this laboratory. [2] Barely alkaline.

Fiber-board manufacturers would do well to pay more attention to the reaction of their waste liquors. A few drops of 1 per cent phenolphthalein in 50 per cent alcohol dropped into about a quarter of an ounce of the waste liquor should produce an intense red color at once.

MILL TESTS ON THE MANUFACTURE OF FIBER BOARD.

Fiber-board mill tests were again undertaken in a fiber-board mill in Maine, but flax tow was used instead of the straw that was employed in the previous work. The regular machines were used in all of these tests and the work was performed by the regular mill employees; in other words, the flax tow was subjected to actual commercial manufacturing conditions, although in some of the tests slight changes in procedure were made, as will be shown.

Bleach No. 234.—A charge of 4,062 pounds was treated with 14.6 per cent of burned lime by slaking 578 pounds of the lime in 1,600 gallons of water in the bleach boiler, then adding the charge of tow. Direct steam was admitted, and the pressure was brought up to 110 pounds in 3 hours and maintained for 4 hours, after which the pressure was relieved in 2 hours and the charge dumped.

After remaining on the drain floor over night this stock was made into a 500-pound beater furnish of one-third flax tow, one-third mixed strings, and one-third board cuttings, in the following manner: The mixture of tow and mixed string was washed in the beater for 2 hours, when the board cuttings and sulphite screenings were added and the charge beaten off in a total of 12 hours. Near the end of the beating, the filler, color, and size were added. This stock was run over a 44-inch wet machine, loft dried, and put through the board calenders. The wet boards from the wet machines measured 38 by 44 inches, and after they were dried and calendered they measured 33 by 44 inches, which is about the correct amount of shrinkage. These boards were sold in the trade, but not as counter boards, as they were too brittle for that grade. The brittleness was due, according to the management and employees, to the fact that the stock was beaten too short. In working with any new material, its characteristics and differences must be learned before its full possibilities can be developed, and many failures must be expected during the earlier stages of development.

Bleach No. 235.—This bleach was made in the same manner as No. 234, but 15 per cent of lime was used and the charge cooked at a steam pressure of 75 pounds for 9 hours, the total time of cooking being 12 hours. The stock from this bleach was used in the same furnish and manner as that of bleach No. 234. This furnish was beaten off in a total of 12 hours, loaded, colored, and sized, as in the previous test. The stock showed up very well in going over the wet machine, giving a board measuring 38 by 44 inches wet, which after loft drying and calendering measured 33 by 44 inches. This

board was pronounced by the fiber-board employees and the management officials to be equal to those boards of this class in which imported flax waste is used, and it was sold on the market by the cooperating mill as a second-grade counter board at the regular price of such boards, namely, 5 to 5½ cents per pound (fig. 8).

The thin boards of this run were somewhat soft and the thick boards were somewhat brittle, which naturally would be the case, since each thickness of board requires that the stock be beaten accordingly.

Additional tests.—Three other complete tests were made like the two above recorded, and although the results were not as satisfactory as those of No. 235, the board was sold as second-grade counter board and no complaint has been received from it.

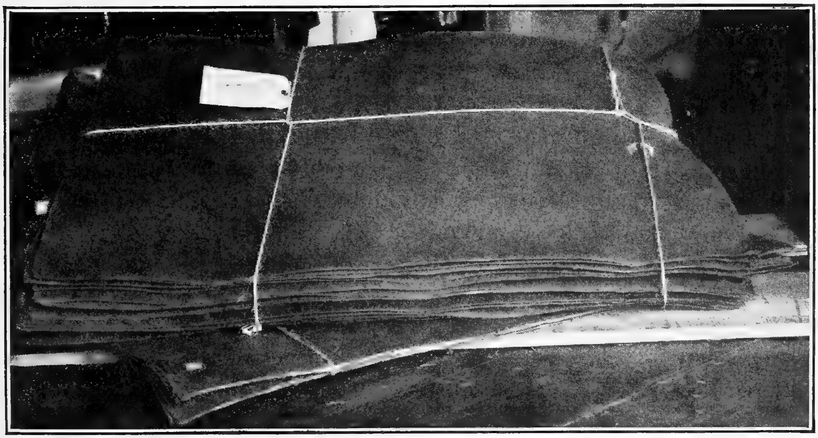

FIG. 8.—A package of counter boards, in the manufacture of which domestic flax upholstering tow was employed in place of imported flax waste. Size of boards, 33 by 44 inches.

Unfortunately, no methods of testing boards have been devised which give the results as a numerical expression, the usual method being to bend and fold the board with the fingers in different manners, according to the use to which the board is to be employed, and noting the degree with which it breaks or cracks.

YIELD OF PRODUCT AND COMPARATIVE COSTS.

It is impossible in the mill tests to determine the yield of washed or available fiber derived from the straw and tow, even as compared with imported flax waste. The general opinion of the management and employees who followed the tests was that there was no appreciable difference in yield so far as could be determined by observation during the tests.

Laboratory determinations of the yield of washed fiber on 6-pound samples of flax straw, medium flax tow, and the best grade of imported flax waste gave the results shown in Table VIII.

TABLE VIII.—*Yield of washed fiber from flax straw, medium tow, and imported flax waste.*

Material tested.	Lime used.	Time of treatment.	Pressure per square inch.	Yield of washed fiber.
	Per cent.	*Hours.*	*Pounds.*	*Per cent.*
Flax straw	18	6	100	41.2
Medium flax tow	17	5	100	50.4
Imported flax waste	10	10	45	55.7

It should be remembered that these are experimental results, and although necessarily they do not represent the mill yields, they are strictly comparative. Probably the yields are lower than those in mill practice. Although domestic flax tow yields a lower percentage of washed fiber than does imported flax waste, the lower price paid for the former makes the total cost of the washed product made from domestic tow delivered as far east as Boston very little more than the total cost of washed fiber produced from imported waste. It would thus appear that, so far as both cost and quality of product are concerned, the domestic flax tow from the region of the Dakotas can compete against imported flax waste in the manufacture of counter boards even if the manufacture is conducted as far east as Boston. If the board manufacture is conducted near the flax region, the results would be about as 7 to 5 in favor of domestic tow.

SUGGESTIONS FOR FLAX FARMERS.

Many letters have been received from the farmers of the flax region asking for information in regard to the profitable disposal or utilization of their waste flax straw.

So far as its use in the paper industry is concerned, it is obvious that no immediate benefit can be derived until its value in this line is proved and industries are established which will create a market for it. The success of the project depends to a certain extent upon the farmer. The price of his straw must net him a fair profit, but at the same time this price must be such that the material will be attractive to the paper manufacturer. When the time comes that the paper industry will be in a position to use this material the flax farmer should have made arrangements to supply the material in such a manner that he may secure his proper proportion of the benefits and profits.

It would seem, from the paper-maker's as well as the farmer's standpoint, that the most beneficial and profitable as well as generally satisfactory method of assembling this material for the market would be to establish a number of small tow mills throughout the region where the most flax is grown rather than to establish a smaller number of larger tow mills. This method would render more material available, benefit more farmers, and place the product on the market at a lower price.

As a suggestion for consideration, farmers may find it advisable to act cooperatively. For example, the farmers within a 5-mile radius might own and operate a tow mill of sufficient capacity to market the entire quantity of straw within their area. Under this system the farmer not only would benefit by the sale of his straw but would receive also a profit from the manufacture of the tow.

From present indications it appears that different grades of tow should be produced for the paper industry, depending on the grade of paper to be manufactured. For example, a medium grade of tow might answer the requirements of the board manufacturer, while a fine or extra fine grade would be required by the wrapping-paper manufacturer. Investigation doubtless will be continued along the wrapping-paper and writing-paper lines, in order to develop a market which will absorb an appreciable amount of this large and potentially valuable crop waste.

CONCLUSIONS.

Should flax straw or tow prove to be of value to the paper or board industry, the condition of the raw-material market at the present time is such that the new supply would be very welcome to the trade. Since this work was undertaken, many calls for information have been received from the mills and many offers of cooperative help have been extended, which show conclusively the attitude and needs of the industry.

If, as seems very probable, domestic flax straw or tow can replace imported flax waste in the manufacture of counter boards, it should open up a market for about 20,000 tons of straw, which, although a small amount, is a step in the direction of the advancement of home industry.

Should the straw be able to compete successfully in the manufacture of writing papers it should open up a market of between 200,000 and 400,000 tons of straw per annum, the sale of which would represent an added revenue to the flax region of $800,000 to $1,600,000. This country is importing over $2,000,000 worth of rags per annum, which are used largely in the manufacture of writing papers.

The wrapping and bag paper lines offer like possibilities, which are worth consideration in this general project.

The flax crop, which furnishes normally $33,000,000 worth of flax seed, yields about 1,400,000 tons of straw, which is put to no profitable use and for the most part is burned in the fields. It is purely a waste product and, moreover, one which is already assembled to a large degree. It has always been a migratory crop, but increased knowledge of its nature and proper methods of raising are beginning to check this condition. Moreover, if the flax farmer who realizes $12 per acre for his seed can deliver his straw at tow mills or other central points for, say, $4 per ton, he is realizing an increased revenue

per acre of 25 per cent, which fact also will exert a restraining tendency on the migration of the crop.

Of this large crop waste, 91 per cent is raised in the following States: North Dakota, 43.7 per cent; Minnesota, 16.1 per cent; South Dakota, 15.7 per cent; and Montana, 15.3 per cent. From the total of 1,600,000 tons of flax straw not over 200,000 tons are put to a profitable use in the manufacture of flax tow and insulating material. Many fruitless attempts to utilize this straw in paper manufacture have been made, but thus far no permanent industries have resulted.

In the manufacture of fiber counter boards used in shoe manufacture, there are used annually about 7,000 tons of flax waste imported from Europe. Since the outbreak of the European war the importation of this material has been curtailed and its price has advanced 100 per cent. For these reasons, among others, the Department of Agriculture has investigated the adaptability of domestic flax for supplying this market. As the result of laboratory and commercial cooperative tests in a counter-board mill, counter boards were produced, employing domestic flax tow in place of imported flax waste, which were pronounced satisfactory and were actually sold by the mill to the trade for counter manufacture at the regular price of counter boards, namely, 5 to 5½ cents per pound.

Flax tow manufactured in the flax region can compete more successfully than can flax straw with imported flax waste, and, as all counter board is of eastern manufacture, it would seem logical to consider its manufacture near the source of flax-straw supply and near the large and increasing Middle West market. The farmer in the flax regions would then be situated most favorably for the marketing of his flax straw.

It is realized that this source of utilization would open a market for not over 20,000 tons of straw annually. It is proposed, therefore, to extend this investigation into the lines of wrapping and writing paper manufacture. If successful methods of so using flax straw and tow are discovered, a large proportion of this great and potentially valuable crop waste could be utilized. This not only would benefit the farmer but would exert a very strong tendency toward maintaining the flax crop in our system of agriculture.

The attention of the Department of Agriculture has been called repeatedly to various schemes which have been promoted by individuals and organizations in attempts to lead the farmer to believe that there are demands for flax straw greater than careful investigation has shown to exist. The farmer is advised, therefore, to investigate carefully any schemes which have not been thoroughly tested and found to be of practical value by reputable manufacturers.

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